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A bi-objective integrated procurement, production, and distribution problem of a multi-echelon supply chain network design: A new tuned MOEA

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ABSTRACT

Efficient management of supply chain (SC) requires systematic considerations of miscellaneous issues in its comprehensive version. In this paper, a multi-periodic structure is developed for a supply chain network design (SCND) involving suppliers, factories, distribution centers (DCs), and retailers. The nature of the logistic decisions is tactical that encompasses procurement of raw materials from suppliers, production of finished product at factories, distribution of finished product to retailers via DCs, and the storage of raw materials and end product at factories and DCs. Besides, to make the structure more comprehensive, a flow-shop scheduling model in manufacturing part of the SC is integrated in order to obtain optimal delivery time of the product that consists of the makespan and the ship time of the product to DCs via factories. Moreover, to make the model more realistic, shortage in the form of backorder can occur in each period. The two objectives are minimizing the total SC costs as well as minimizing the average tardiness of product to DCs. The obtained model is a bi-objective mixed-integer non-linear programming (MINLP) model that is shown to belong to NP-Hard class of the optimization problems. Thus, a novel algorithm, called multi-objective biogeography based optimization (MOBBO) with tuned parameters is presented to find a near-optimum solution. As there is no benchmark available in the literature, the parameter-tuned multi-objective simulated annealing algorithm (MOSA) and the popular non-dominated sorting genetic algorithm (NSGA-II) are developed to validate the results obtained and to evaluate the performance of MOBBO using randomly generated test instances.

1. Introduction

Supply chain (SC) is a systematic concept that encompasses different terms, from raw material supplying via upstairs suppliers to downstairs distributers and customers. This systematic concept is defined as a network of facilities that supply raw material that are transformed into intermediate and final products, and finally, distributed between customers. The component of general SCs are suppliers, manufacturers, distribution centers (DCs), retailers, and customers [1]. Moreover, SCs generally include two main interrelated processes of (1) production planning and inventory control that deal with production, storage, and relation between them, and (2) logistics and distribution that determine how to transport products to customers and to recycle them. Correspondingly, cost terms are defined in different part of the SCs, including resource cost, transportation cost, cost of transforming raw materials to final products, cost of delivering the products to customers, and cost of various servicing terms [2].

In the literature of supply chain network design (SCND) problems, most researchers focused on cost as criterion to measure supply-chain performances. However, another fundamental measure is responsiveness, where the lead-time and reacting quickly to meet market demands can find a great attention. Note that responsiveness and cost conflict with each other. In other words, a responsive SC usually has a higher cost, while a cost-oriented SC often operates at the expense of market responsiveness [3,4]. The above two performance metrics of SC are crucial to SCND.

Fahimnia et al. [5] presented a whole set of integrated production and distribution planning model of supply chain networks (SCNs) in different categories, of which one is the solution

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methodology. As the search effort to find the optimal solution in integrated SC problems may require long CPU time, selecting an effective optimization technique is prominent. The solving methodologies of these problems are classified into four categories including (1) mathematical techniques [5], (2) heuristic methods, (3) simulation, and (4) meta-heuristic algorithms [6]. As this research focuses on three of these techniques, namely the first, the second, and the fourth, a brief relevant review of them in both the single-objective and multi-objective problems is given as follows.

Haq et al. [7] proposed an integrated production-inventory-distribution model incorporating many realistic conditions to determine optimal production and distribution as well as inventory level, where a mixed-integer-linear programming (MILP) was developed to minimize the total cost of the system. Barbarosoglu and Ozgur [8] used the Lagrangian relaxation method in hierarchical design of an integrated production–distribution in a 2-echelon system, where a MILP was presented to minimize the total fixed and variable costs. Chen and lee [9] presented a multi-product multi-stage multi-period model with multiple incommensurable goals of a multi-echelon SCN as a mixed-integer nonlinear programming problem, where fuzzy sets were considered to describe the uncertain nature of demands and product prices. Selim et al. [10] developed a multi-objective linear programming model to collaborate production-distribution planning problem (PDPP) in SC. A fuzzy goal programming was considered to incorporate decision maker's imprecise aspiration levels. Ferrio and Wassick [11] considered a multi-product chemical supply network including production sites, an arbitrary number of DCs, and customers and formulated the problem as a MILP model for redesigning and optimizing of the network. The problem was analyzed using the GAMS/CPLEX mathematical programming solver. Tuzkaya and Onut [12] presented an integrated model to determine the best strategy of distributing sub-products between a supplier, warehouses, and manufacturers. The objective was to minimize total costs of inventory, warehouse, manufacturer, and penalty cost for supplier, manufacturers, and warehouses. Jolayemi [13] presented an integrated MILP model with factories, DCs, and retailers for determining the optimal quantities of products to be produced, optimum inventory holding in factories, optimal transportation quantities to DCs, optimal inventory holding in DCs, and optimal quantities transported to retailers in each period. The model was introduced as production–distribution and transportation planning problem, where two versions, the fully optimized version (FOV) and the less fully optimized (LFOV), were considered to be solved. Pishvaee and Razmi [14] proposed an interactive fuzzy solution approach to solve a multi-objective fuzzy mathematical programming model of an environmental SCND with objectives of minimizing total cost and minimization of the total environmental impact. Bashiri et al. [15] presented a new multi-product mathematical model with strategic and tactical planning and different time resolution decisions for a multi-echelon network. This model was categorized in small, medium, and large scales and was solved by the CPLEX solver for small and medium size problems, and by some heuristics to decrease solution time of solving large scale problems. Sadjadi and Davoudpour [16] proposed an efficient Lagrangian method to solve a two-echelon SCND problem. The problem was designed in both strategic and tactical levels of SC planning in deterministic, single period, and multi-commodity contexts, and was formulated as a mixed-integer programming (MIP) model to minimize total costs of the network. Badri et al. [17] developed a new multi-commodity SCND model with different time resolutions for strategic and tactical decisions. The objective function was to maximize the total net income over the time. In addition, a mathematical technique based on the Lagrangian relaxation method was developed to solve the problem. Finally, Liu and Papageorgiou [4] proposed a multi-objective production–distribution and capacity planning model by considering costs, response, and service level in a universal SC. Their problem was solved by means of the ε-constraints and Lexicographic mini–max methods.

As most of realistic SC models are complex in nature with a high number of variables and constraints, mathematical optimization methods such as linear programming (LP) and MIP may not be very effective for solution [6]. Furthermore, due to exponential growth of the problem size and complexity, the problem becomes NP-Hard and long CPU time is required to solve it using mathematical programming algorithms [18,19]. Hence, heuristic and meta-heuristic algorithms are used to solve them. In this regard, Syarif et al. [20] designed a multi-echelon SCN in order to select the plants and DCs to be opened in a distribution network to satisfy the demand. They solved the problem using a spanning-tree-based Genetic algorithm (GA). Park et al. [18] proposed a multi-period multi-product SC model, including supplier, factory, and distribution center to minimize the total cost and presented a GA to solve the problem. Altiparmak et al. [21] presented a multi-objective network structure of manufacturers and customers in which shortage is forbidden. The minimization of total costs and delivery time and balancing the capacity of the factories were objective functions in this problem. The objectives' weights were determined using an analytic hierarchy process (AHP) and a GA was utilized to solve the problem. Kazemi et al. [22] proposed a multi-level SC with two scenarios for making production–distribution decisions. Considering interplay of the levels, a multi-agent system based on GA for each level was proposed as the solution algorithm. Chang [23] designed a multi-echelon SCN including suppliers, factories, DCs, and retailers for minimizing the total costs of chain including purchasing and transportation cost of raw materials and products, manufacturing of products in factories, and storage cost of products in DCs. In order to find a solution rapidly, a GA with optimum search features combined with a co-evolutionary mode and constraint-satisfaction was used. Amrani et al. [24] presented a multi-commodity production–distribution network with alternative facility configuration. The problem was formulated as a MIP model and solved using a variable neighborhood search (VNS) method. Jolai et al. [19] developed a linear multi-objective production–distribution model in a SCN with several products, levels, and periods. The decision maker's imprecise aspiration levels of goals were incorporated into the model using a fuzzy goal programming approach and solved using three meta-heuristics with a new fitness function in GA and particle swarm optimization (PSO), and an improved hybrid GA as well. Pourrousta et al. [25] presented a bi-objective production–distribution planning in a SCN by considering uncertainly of different parameters using trapezoid numbers. The objective functions aimed to minimize total costs and delivery time of products to customers. A ranking method was first implemented to convert the fuzzy model into a crisp, and then a multi-objective particle swarm optimization (MOPSO) was employed to solve the problem. The performances of MOPSO were compared with the ones of a non-dominated sorting genetic algorithm (NSGA-II) for some randomly generated problems.

Based on a systematic view of a SC, a multi-period multi-objective SCND involving suppliers, factories, DCs, and retailers is modeled in this paper, in which maximizing service level is taking into account by considering shortages that are backordered. The other contributions of this work to the literature are:

1. In most of the bi-level or multi-level supply chain networks of the literature that include a manufacturing level, some random numbers are generated for the due date and the complementation times of the manufacturing process and inserted into the model. However, in this research the manufacturing level is